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PERCEPTUAL AND PHYSIOLOGICAL RESPONSES DURING EXERCISE IN COOL AND COLD WATER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This investigation examined the interaction of exposure to cold water stress with both perceived exertion and themal sensation during exercise. Eight male volunteers performed arm, leg and combined arm and leg exercise for 45 min in water at 20 and 26°C. Exercise was performed at a low (n=7) and a high (n=8) intensity relative to the ergometer specific peak oxygen uptake ($\dot{V}O_2$ peak). In general, percent $\dot{V}O_2$ peak did not differ ($p>0.05$) between types of exercise in either 20 or 26°C water. During low intensity exercise when power output was matched across water temperatures (T_w), percent $\dot{V}O_2$ peak was greater

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($p<0.05$) in 20°C water (52%) compared to 26°C water (42%). Ratings of perceived exertion (RPE) did not differ ($p>0.05$) between T_W. During high intensity exercise when percent $\dot{V}O_2$ peak was matched across T_W, RPE was lower ($p<0.01$) during exercise in 20°C ($\bar{X}=12.9$) compared to 26°C ($\bar{X}=13.9$). Multiple correlation analyses comparing both final RPE and thermal sensation (TS) with physiological and thermal measures were performed across type of exercise and T_W. RPE was moderately correlated with heart rate ($r=0.68$) and ventilation ($r=0.61$), whereas very slight relationships were established with TS ($r=0.16$), skin and rectal temperatures ($r=0.10$ and $r=0.20$). TS was moderately correlated with skin and rectal temperatures ($r=0.64$ and $r=0.73$), whereas low correlations existed between TS and both heart rate ($r=0.32$) and ventilation ($r=0.12$). These data suggest that the change in oxygen uptake associated with exercise in cold water does not add to the overall perception of exertion. This perception appears to be related to cardiopulmonary variables rather than thermal measures, whereas thermal sensation is related to thermal measures and not cardiopulmonary variables.

(TS)

Summary- This investigation examined the interaction of exposure to cold water stress with both perceived exertion and thermal sensation (TS) during exercise. Eight male volunteers performed arm, leg and combined arm and leg exercise for 45 min in water at 20 and 26°C. Exercise was performed at a low ~~(n=7)~~ and a high ~~(n=8)~~ intensity relative to the ergometer specific peak oxygen uptake ($\dot{V}O_2$ peak). In general, percent $\dot{V}O_2$ peak did not differ ($p > 0.05$) between types of exercise in either 20 or 26°C water. During low intensity exercise when power output was matched across water temperatures (T_W), percent $\dot{V}O_2$ peak was greater ($p < 0.05$) in 20°C water (52%) compared to 26°C water (42%). Ratings of perceived exertion (RPE) did not differ ($p > 0.05$) between T_W. During high intensity exercise when percent $\dot{V}O_2$ peak was matched across T_W, RPE was lower ~~($p < 0.01$)~~ during exercise in 20°C ~~($\bar{X}$=12.9)~~ compared to 26°C ~~($\bar{X}$=13.9)~~. Multiple correlation analyses comparing both final RPE and thermal sensation ~~(TS)~~ with physiological and thermal measures were performed across type of exercise and T_W. RPE was moderately correlated with heart rate ~~(r=0.68)~~ and ventilation ~~(r=0.61)~~, whereas very slight relationships were established with TS ~~(r=0.18)~~, skin and rectal temperatures ~~(r=0.10 and r=0.29)~~. TS was moderately correlated with skin and rectal temperatures ~~(r=0.64 and r=0.73)~~, whereas low correlations existed between TS and both heart rate ~~(r=0.32)~~ and ventilation ~~(r=-0.12)~~. These data suggest that the change in oxygen uptake associated with exercise in cold water does not add to the overall perception of exertion. This perception appears to be related to cardiopulmonary variables rather than thermal measures, whereas thermal sensation is related to thermal measures and not cardiopulmonary variables.

Key words: ~~Perceived exertion, thermal sensation,~~ relative oxygen uptake; water immersion, ~~rectal temperatur~~ ~~in temperature,~~ heart rate; ~~ventilation~~

In the early 1960s Borg suggested that the perception of effort was an integration of multiple sensory information into a gestalt reflecting the overall perceived exertion (Borg, 1962). Investigators have since attempted to identify and describe the complex mechanism underlying the sense of effort. These findings concerning perceived exertion have most recently been reviewed by Pandolf (1983). In this regard several approaches have been used to identify the primary physiological and psychological cues involved in the effort sense. Several studies have controlled or manipulated physiological variables during exercise by the use of pharmacological agents (Davies & Sargeant, 1979; Sjöberg, et al., 1979; Van Herwaarden, et al., 1979), hypnosis (Morgan, et al., 1976; Morgan et al., 1973), hyperoxia (Allen & Pandolf, 1977) and environmental conditions (Kamon, et al., 1973; Pandolf, et al., 1972; Skinner, et al., 1973; Young, et al., 1982) in an attempt to uncover these cues.

Whereas environmental heat and high altitude have been examined regarding the effort and/or thermal sense, to our knowledge there have been no reports that have used cold as an experimental condition to examine the relationship between selective physiological and perceptual variables. Cold water provides a unique circumstance whereby oxygen uptake can be elevated and heart rate maintained at any exercise power output. In addition, the thermal strain placed on the individual is sufficient to examine the possible interaction of thermal physiological and sentient factors with the cognition of effort.

The purpose of the present study therefore was to examine the relationship between physiological and perceptual variables over time and across water temperature during various modes of dynamic exercise. With strict regard to the cognitive factors, it was hypothesized that the thermal stress in cold water may alter the individual's perception of effort during exercise and should certainly alter his perception of thermal stress.

METHODS

Subjects. Eight males volunteered for the water immersion study. The average age, height, and weight of the group was 22.4 $\pm$ 3.6 (SD) years, 171.1 $\pm$ 5.0 cm, and 70.9 $\pm$ 6.2 kg, respectively. Subjects were medically cleared for participation in all aspects of the experimental procedures. Each were advised of the risks of the testing procedures and each gave written informed consent. These individuals were unacclimated to the environmental conditions of the study prior to their participation.

Protocol. Prior to the experimental sessions, each subject was familiarized with the test equipment and procedure. Exercise was performed on an arm-leg ergometer that was designed for both air and water usage (Toner, et al., 1984). In addition to familiarization on the arm-leg ergometer, subjects were evaluated for peak aerobic power (peak $\dot{V}O_2$) during arm, leg, and combined arm-leg exercise modes. Peak $\dot{V}O_2$ tests in air for these exercise modes have previously been described and the values reported (Toner, et al., 1984). From these results, low and high exercise intensities that were approximately 40 and 60 % of the peak $\dot{V}O_2$ for each type of exercise were chosen for the water experiments.

As illustrated in Figure 1, equivalent power outputs were performed for each exercise type in water at 20 and 26°C. Since exercise in cold water elevates oxygen uptake above control values in warm water, the high intensity matched the oxygen uptakes between the 20 and 26°C water temperatures by reducing the power outputs in the 20°C exposure. All water experiments consisted of 45 min of continuous exercise with each mode and in each temperature of water; therefore, each subject performed six experimental tests. Measurements of oxygen uptake, pulmonary ventilation, rectal and skin

temperatures, and heart rate were obtained at 5, 15, 30, and 45 min and each determination was based on 1-min samples. Responses of thermal sensations and ratings of perceived exertion were requested by standardized procedures and obtained immediately following expired air collections.

Insert Figure 1 About Here

Physiological and Perceptual Measures. Oxygen uptake ($\dot{V}O_2$) was determined by standard techniques of open-circuit spirometry. Expired air was collected in Douglas bags and was analyzed for O_2 (Applied-Electrochemistry, S-3A) and CO_2 (Beckman, LB-2) concentrations. Air volumes were measured by evacuation of the Douglas bags into a 120-liter Tissot spirometer; these volumes were corrected to standard conditions for calculation of $\dot{V}O_2$. Heart rate was determined by ECG records obtained during the final 15 sec of expired air collection. The bipolar lead placement was in the CM-5 position.

Mean skin temperature ($\bar{T}_{sk}$) of the immersed portion of the body was obtained by area weighting of nine skin thermocouples as follows: $\bar{T}_{sk} = 0.06\ T_{foot} + 0.17\ T_{calf} + 0.14\ T_{medial\ thigh} + 0.14\ T_{lateral\ thigh} + 0.14\ T_{chest} + 0.07\ T_{triceps} + 0.07\ T_{forearm} + 0.14\ T_{back} + 0.07\ T_{hand}$. All skin thermocouples were applied with one layer of adhesive tape. (Hy-tape, New York, NY) covering the sensor. Rectal temperature (T_{re}) was measured by a thermistor probe inserted 10 cm into the rectum. Temperature measurements were recorded by a Hewlett-Packard 9825 B calculator following processing through both a Hewlett-Packard 3456 A digital voltmeter ($\pm$ 0.1 µV accuracy) and 3495 A scanner.

Ratings of perceived exertion were obtained from the subjects by use of the 15 point category scale developed by Borg (1970). During the rating periods,

subjects were asked to integrate their "local" muscular and "central" cardiorespiratory feelings into a general sensation of effort. Weighting of "local" and "central" components was left to the discretion of the subject. Table 1 illustrates the thermal sensation scale used in the present study which was modified from the scale used by Gagge, et al. (1967).

Insert Table 1 About Here

Statistical Analysis. Metabolic, thermal and perceptual values were analyzed by a 2 way repeated measures analysis of variance. Significant F-ratios were futher evaluated by the Tukey post hoc test to determine differences between means (Cicchetti, 1972). Metabolic, thermal and perceptual data were entered into a stepwise regression model to evaluate the relationship between variables. The 0.05 level of confidence was used in all statistical procedures.

RESULTS

As illustrated in Figure 2 (left), oxygen uptake as a percent of peak $\dot{V}O_2$ (%$\dot{V}O_2$) at min 45 was not different ($p > 0.05$) between exercise modes in either 20 or 26°C water during the low intensity exercise. Ratings of perceived exertion (RPE) were higher ($p < 0.05$) during leg exercise compared with arm and combined arm-leg exercise in both 20 and 26°C. The %$\dot{V}O_2$ was significantly higher in 20°C compared with 26°C water; in contrast , despite higher %$\dot{V}O_2$ there were no differences ($p > 0.05$) in RPE between either 20 or 26°C across all exercise modes. As shown in Figure 2 (right) during high intensity exercise, there were no differences ($p > 0.05$) in %$\dot{V}O_2$ between exercise modes ether 20 and 26°C water. RPE was higher ($p < 0.05$) during leg compared with both arm and combined arm-leg exercise in both 20 and 26°C water. Despite similar

$\%\dot{V}O_2$ between 20 and 26°C conditions, RPE was significantly higher in 26°C compared with 20°C water.

Insert Figures 2A and B About Here

Figure 3 (left) illustrates $\%\dot{V}O_2$, rectal temperature (T_{re}), heart rate (HR) and RPE during low intensity exercise in water at 20 and 26°C as a function of exercise time. In 20°C water, T_{re} declined ($p < 0.05$) throughout the immersion period whereas there was no change across time in 26°C water. Complimenting the declining T_{re} in 20°C, $\%\dot{V}O_2$ increased throughout the exposure. In 26°C, the $\%\dot{V}O_2$ decreased slightly throughout the 45 min of immersion. In contrast to the diverging $\%\dot{V}O_2$ and T_{re} responses in the 20 and 26°C tests, HR and RPE values showed no differences ($p > 0.05$) between the 20 and 26°C conditions. Also there were no changes in HR or RPE across time in either water. Figure 3 (right) illustrates T_{re}, $\%\dot{V}O_2$, HR, and RPE over time during high intensity exercise. In 20°C water, T_{re} declined slightly with time whereas in 26°C T_{re} increased steadily ($p < 0.05$) throughout the immersion period. The $\%\dot{V}O_2$ remained unchanged with time in both T_w, and there were no differences ($p > 0.05$) between the 20 and 26°C water. HR increased slightly with time in 26°C whereas there was no change with time in 20°C water. HR was 5 to 12 beats per minute higher in 26 compared with 20°C exposures. In contrast to the diverging T_{re} seen between the 20 and 26°C tests, as well as, no differences in $\%\dot{V}O_2$ between each T_w, RPE steadily increased and was statistically higher in 26°C compared to the same time in 20°C .

Insert Figures 3A and 3B About Here

Insert Table 2 About Here

Table 2 examines the relationship between the different physiological and perceptual variables. The three types of exercise and both T_w were combined in one analysis to generate these correlational coefficients. There were moderate ($p < 0.05$) correlations between the cardiopulmonary variables of HR, ventilation and oxygen uptake with RPE. Slight relationships ($p > 0.05$) were established between T_{re} and $\bar{T}_{sk}$ with RPE. In contrast, thermal variables of T_{re} and $\bar{T}_{sk}$ were moderately correlated ($p < 0.05$) with thermal sensation, whereas little correlation was established between the cardiopulmonary variables and thermal sensation.

DISCUSSION

The physiological cues responsible for the perception of effort have yet to be completely elucidated. Relative oxygen uptake ($\%\dot{V}O_2$) has been suggested as one factor that might be associated with an overall sense of effort (Pandolf, 1983; Sargeant & Davies, 1973). The discrete symptoms of breathing, beating of the heart and/or aching muscles which are a consequence of $\%\dot{V}O_2$ may be organized into cardiopulmonary and local muscular exertional signals that are ultimately integrated into the overall perception (Pandolf, et al., 1975). Controversy does exist however as to the importance of the $\%\dot{V}O_2$ in the effort sense. Buick, et al. (1980) demonstrated with blood reinfusion that alterations in

$\dot{V}O_2$ max had no effect upon RPE for a given exercise level. This is directly in conflict with Robertson (1982) who also used a reinfusion protocol. The data in the present study in part support the observations of Buick, and co-authors. Despite elevations in $\%\dot{V}O_2$, in 20°C compared with 26°C water during low intensity exercise, RPE remained unchanged. Also, during high intensity exercise where power output was lowered in 20°C conditions and $\%\dot{V}O_2$ were similar between both T_w, RPE was reduced on the average across all exercising modes. Responses over time also corroborated the independence of the $\%\dot{V}O_2$ and RPE. During the low intensity exercise, RPE remained unchanged in both 20°C and 26°C water despite a consistent rise of $\%\dot{V}O_2$ in 20°C water, and a fall in 26°C water. During high intensity exercise, RPE increased with time in both T_w whereas there was effectively no change in $\%\dot{V}O_2$ throughout the exposures.

It is plausible that the perception of effort might have been attenuated by the thermal stress of the cold water thereby accounting for the lack of responsiveness of RPE with alterations in $\%\dot{V}O_2$. However, examination of Figure 3 clearly illustrates that the diverging T_{re} responses do not follow the RPE responses. Also since $\bar{T}_{sk}$ was clamped close to T_w, the thermal strain does not appear to have affected the perception of effort. This is supported by the correlations between the physiological variables and rating of effort. Ratings of perceived exertion were not correlated with T_{re} or $\bar{T}_{sk}$ (Table 2), though moderate relationships were established with cardiopulmonary variables. Similarly, thermal sensation was related to T_{re} and $\bar{T}_{sk}$ but not the cardiopulmonary parameters.

The independence of perceptual information (i.e., the thermal and effort sensations) is in part in agreement with others (Pandolf, et al., 1972). Kamon, et

al. (1974) demonstrated that $\bar{T}_{sk}$ correlated with thermal sensation (r=0.71) but not with RPE; whereas the cardiopulmonary variables correlated best with RPE though relationships were established between heart rate and oxygen uptake with TS. Others (Noble, et al., 1973; Pandolf, et al., 1984) have shown that RPE is more highly correlated with cardiopulmonary variables than thermoregulatory responses.

The present findings compliment and extend the work of Morgan (1973) involving the interaction of perception of effort with other psychological states. Morgan (1973) found in general that normal subjects were able to discern differences between power outputs varied by 150 kgm·min^{-1} or greater. However, depressives, neurotics or anxious individuals had difficulty with processing the perceptual cues associated with the exercise (Morgan, 1973). The findings from the present study suggest that exercising individuals, who are presented with additional physiological strain (i.e., cold thermal stress and cold thermal sensation), and consequently added psychological information, are capable of discriminating this information and associating it with selected physiological responses.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on the Use of Volunteers in Research.

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TABLE I. THERMAL SENSATION SCALE

0.0	Unbearably Cold
0.5	
1.0	Very Cold
1.5	
2.0	Cold
2.5	
3.0	Cool
3.5	
4.0	Neutral (Comfortable)
4.5	
5.0	Warm
5.5	
6.0	Hot
6.5	
7.0	Very Hot
7.5	
8.0	Unbearably Hot

TABLE 2. CORRELATION COEFFICIENTS (r) BETWEEN VARIOUS PHYSIOLOGICAL VARIABLES AND EITHER RATED PERCEIVED EXERTION OR THERMAL SENSATION

PHYSIOLOGICAL PARAMETER	RATING OF PERCEIVED EXERTION	THERMAL SENSATION
CARDIOPULMONARY		
HEART RATE	0.68	0.32
VENTILATION	0.61	-0.12
OXYGEN UPTAKE	0.51	-0.10
VENTILATORY EQUIVALENT FOR OXYGEN	0.09	-0.02
THERMAL		
RECTAL TEMPERATURE	0.20	0.73
SKIN TEMPERATURE	0.10	0.64

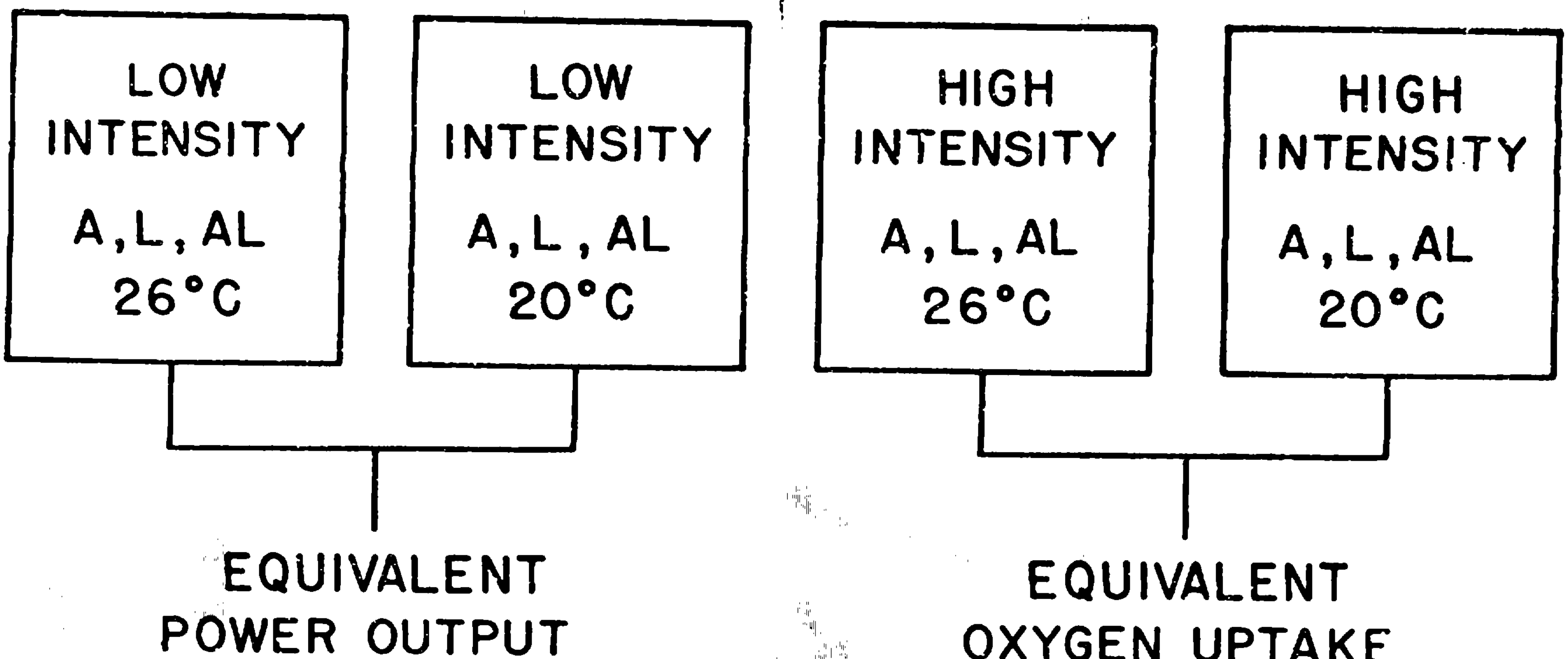
FIGURE LEGENDS

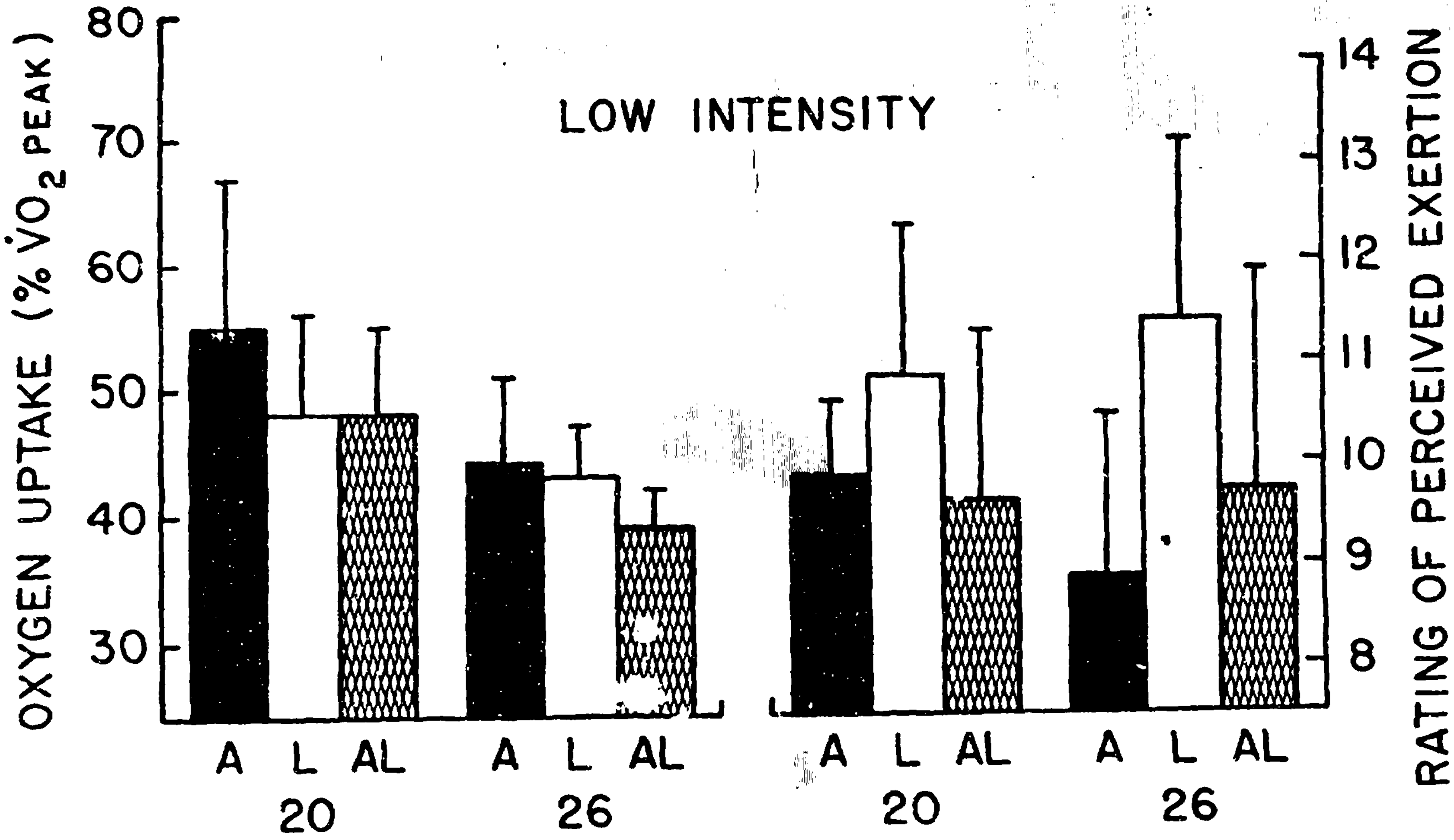
FIG. 1. Experimental design employed showing conditions where power output was equivalent at two different water temperatures (20 and 26°C) for arm (A), leg (L) and combined arm-leg exercise (AL); and, conditions where subjects were exercising at equivalent oxygen uptakes but different water temperatures.

FIG. 2. Oxygen uptake as a percent of peak $\dot{V}O_2$ and ratings of perceived exertion after 45 min for both low (left) and high (right) intensity exercise performed with either the arms (A), legs (L) or combined arms and legs (AL) at water temperatures of 20 and 26°C.

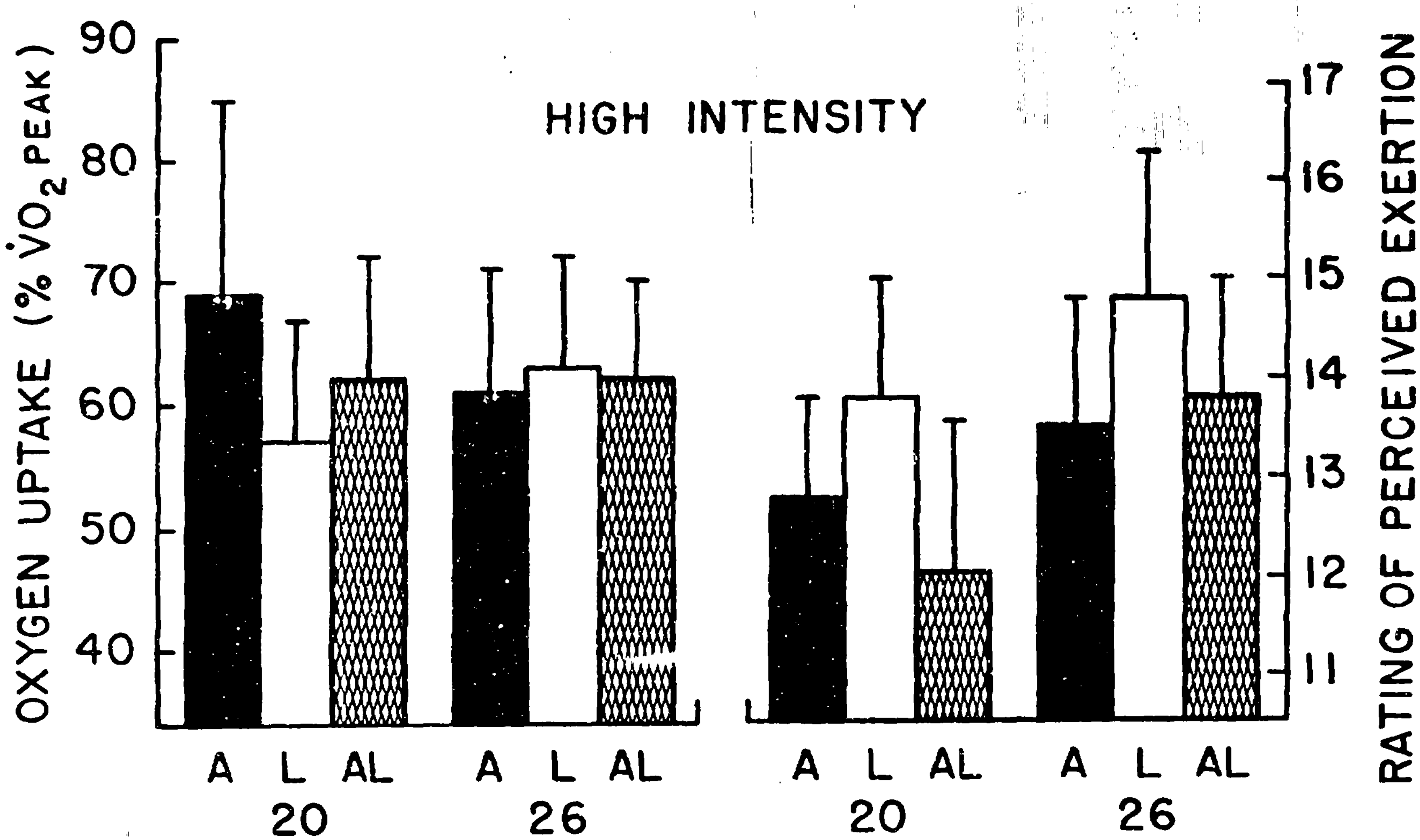
FIG. 3. Rectal temperature, oxygen uptake, heart rate and ratings of perceived exertion over time for both low (left) and high (right) intensity exercise performed at either 20 or 26°C water temperature.

EXPERIMENTAL DESIGN

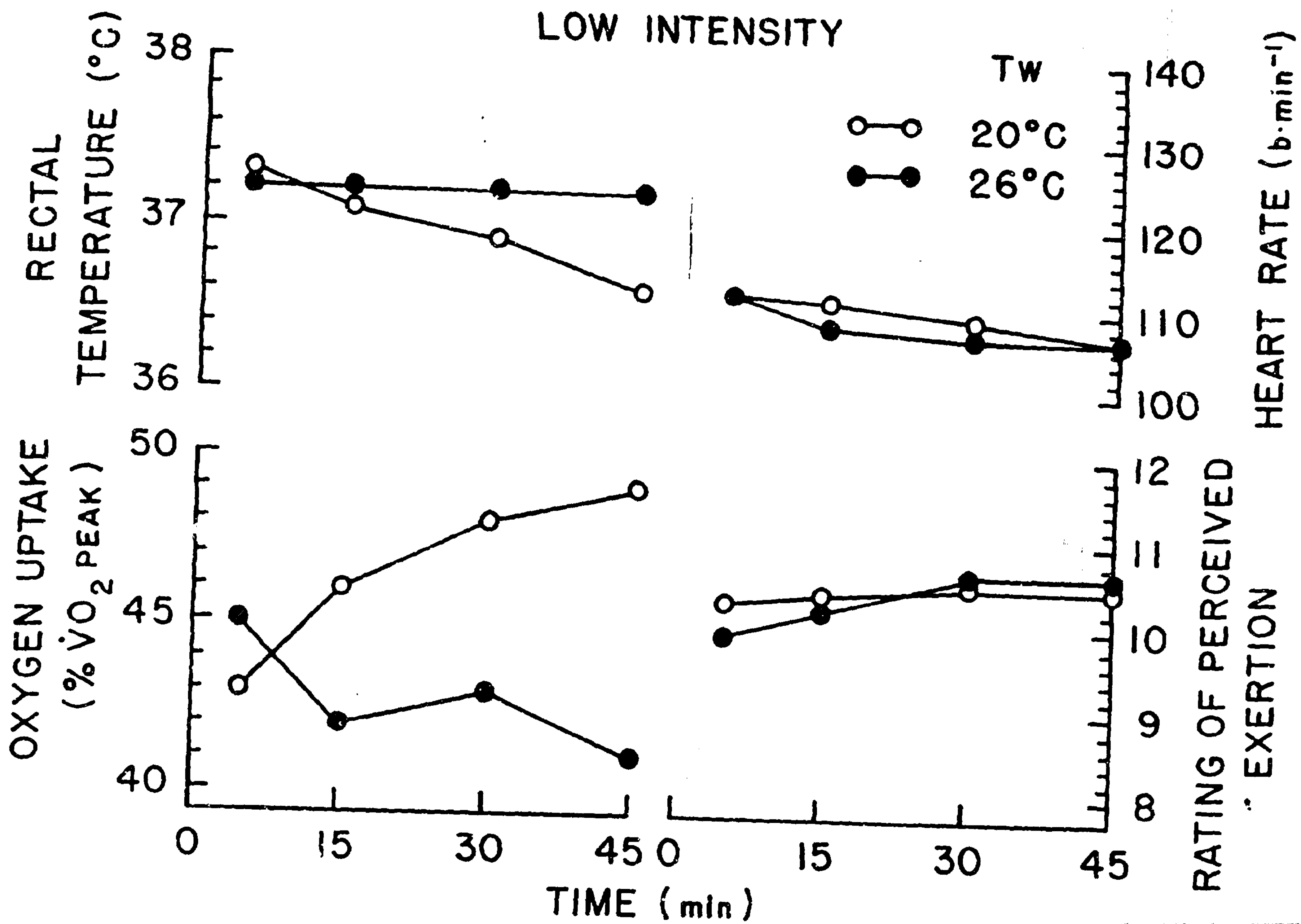


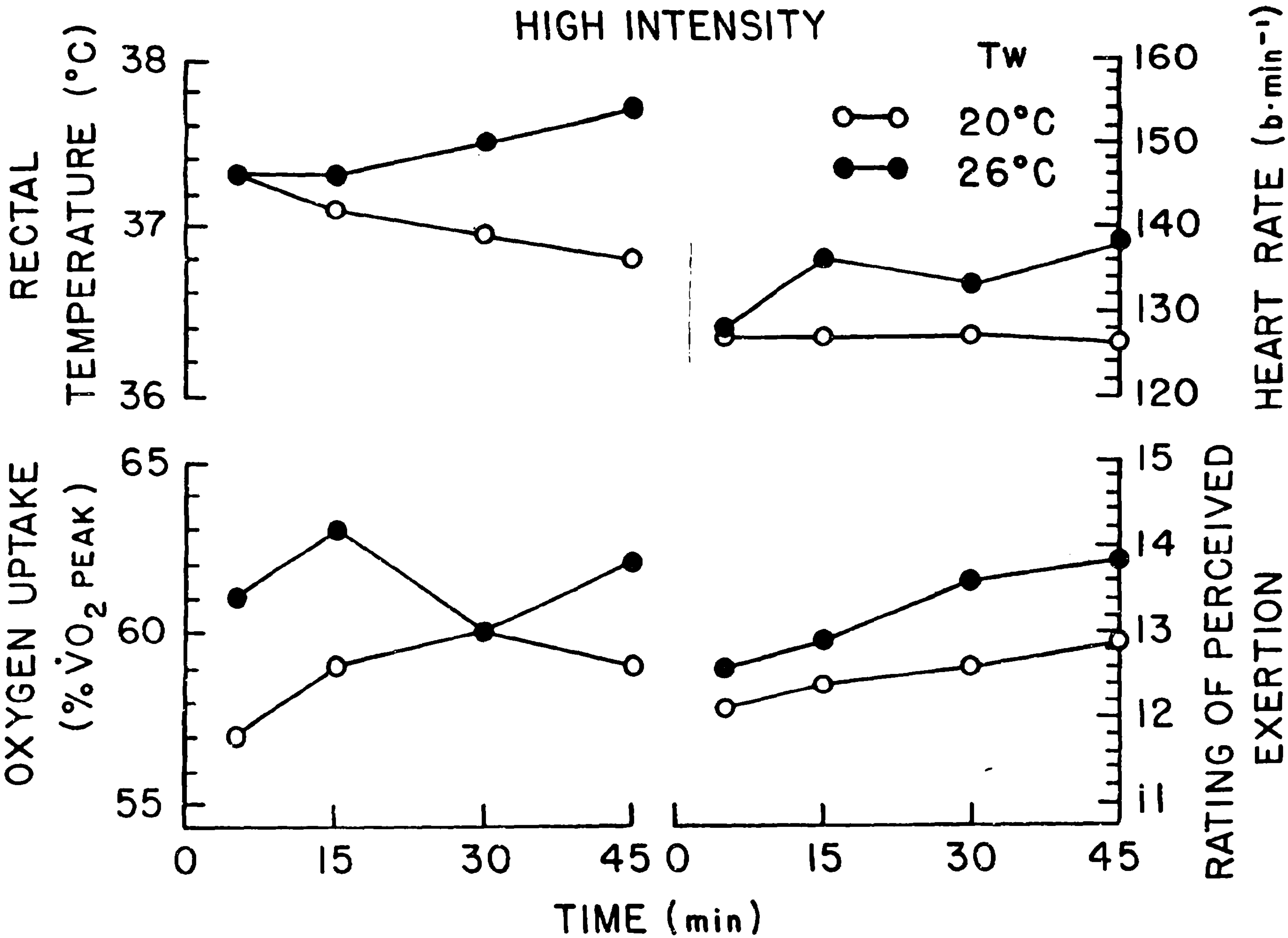


LOW INTENSITY
OXYGEN UPTAKE (% $\dot{V}O_2$ PEAK)
80
70
60
50
40
30
A L AL
20
A L AL
26
A L AL
20
A L AL
26
RATING OF PERCEIVED EXERTION
14
13
12
11
10
9
8



HIGH INTENSITY
OXYGEN UPTAKE (% $\dot{V}O_2$ PEAK)
90
80
70
60
50
40
RATING OF PERCEIVED EXERTION
17
16
15
14
13
12
11
A L AL
20
A L AL
26
A L AL
20
A L AL
26


LOW INTENSITY
Tw
20°C
26°C
RECTAL TEMPERATURE (°C)
38
37
36
HEART RATE (b·min⁻¹)
140
130
120
110
100
OXYGEN UPTAKE (% V̇O2 PEAK)
50
45
40
RATING OF PERCEIVED EXERTION
12
11
10
9
8
0
15
30
45
TIME (min)


HIGH INTENSITY
RECTAL TEMPERATURE (°C)
38
37
36
Tw
20°C
26°C
HEART RATE (b·min⁻¹)
160
150
140
130
120
OXYGEN UPTAKE (% V̇O2 PEAK)
65
60
55
RATING OF PERCEIVED EXERTION
15
14
13
12
11
0
15
30
45
0
15
30
45
TIME (min)